Seeding cool-season grasses into unimproved warm-season pasture in the southern Great Plains of the United States

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Abstract

Limited availability of herbage during the cool season creates a problem of a supply of nutrients for livestock producers throughout the southern Great Plains of the USA and, particularly, on small farms where resource constraints limit possible mitigating strategies. Six cool-season grasses were individually sown into clean-tilled ground, no-till drilled into stubble of Korean lespedeza [*Kummerowia stipulacea* (Maxim) Makino] or no-till over-sown into dormant unimproved warm-season pastures. The dry matter (DM) yields of mixtures of cool and warm-season herbage species were measured to test their potential for increasing cool-season herbage production in a low-input pasture environment. Only mixtures containing Italian ryegrass (*Lolium multiflorum* Lam) produced greater year-round DM yields than undisturbed warm-season pasture with all establishment methods. When cool-season grass was no-till seeded into existing warm-season pasture, there was on average a 0·61 kg DM increase in year-round herbage production for each 1·0 kg DM of cool-season grass herbage produced. Sowing into stubble of Korean lespedeza, or into clean-tilled ground, required 700 or 1400 kg DM ha^{-1}, respectively, of cool-season production before the year-round DM yield of each species equalled that of undisturbed warm-season pasture. Productive pastures of perennial cool-season grasses were not sustained beyond two growing seasons with tall wheatgrass [*Elytrigia elongata* (Host) Nevski], intermediate wheatgrass [*Elytrigia intermedia* (Host) Nevski] and a creeping wheatgrass (*Elytrigia repens L.*) × bluebunch wheatgrass [*Pseudoroegneria spicata* (Pursh)] hybrid. Lack of persistence and low productivity limit the usefulness of cool-season perennial grasses for over-seeding unimproved warm-season pasture in the southern Great Plains.

Keywords: cool-season grasses, warm-season pasture, southern Great Plains, grass yield, persistence

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Introduction

The southern Great Plains of the USA are characterized climatically by an increasing average temperature over a north to south gradient and by decreasing rainfall from east to west (Ojima *et al.*, 1999). There is high inter-annual climate variability and wide seasonal temperature variation. Average annual minimum temperatures in winter range from −20°C to −4°C from north to south across the zone (Cathey, 1990) but average maximum temperatures during the summer months may be greater than 32°C for prolonged periods. Total annual precipitation at the eastern edge of southern Great Plains states (Oklahoma and Texas) exceeds 1140 mm and declines to less than 380 mm in the west. Rainfall has a bimodal distribution, with greatest precipitation in spring and autumn. Reduced rainfall in summer (July and August) is associated with increased temperatures (Zhao and Khalil, 1993). Natural forage resources are predominantly warm-season grasses that have a transition from tall grass prairie in the east, through mixed-grass, to short-grass prairie in the west of the zone, following the rainfall gradient. Depending on the availability of moisture, natural pasture and introduced warm-season grasses can grow actively from April to September, but growth ceases as temperatures decline in the autumn. Provision of herbage during the cool-season period from October to March is thus a problem for many livestock farmers in the southern Great Plains, and increased expenditure on winter feed to counter the problem is closely linked to reduced profitability of livestock enterprises (Ramsey *et al.*, 2005). The shortage of herbage in the cool-season is especially acute for limited-resource small family farms where constraints imposed by an average farm size of 77 ha, household income of US$7200 and dependence on off-farm income (Hoppe and Banker,

2006) limit options for increasing feed supply. Haymaking is likely to be uneconomic for enterprises that harvest less than 80 ha of hay each year (Rogers, 2004), and production of cool-season annual forages, such as wheat (Redmon *et al.*, 1995), may not be possible because of a lack of easy access to equipment necessary for regular cultivation and sowing. Accumulation *in situ* of warm-season herbage for cool-season use is a low-input conservation technique (Evers *et al.*, 2004) that may be appropriate for small livestock producers, but it pre-supposes a farm infrastructure and carrying capacity sufficient to allow areas to be set aside for deferred grazing. The use of introduced cool-season herbages is frequently seen as a means to alleviate the feed deficit, by providing green herbage earlier or later in the year, to allow an extension of the grazing season. Recent research has shown that significant production can be obtained from perennial cool-season species grown in monoculture to complement warm-season perennial grasses or annual cool-season pastures (Malinowski *et al.*, 2003, 2005; Gillen and Berg, 2005; Northup *et al.*, 2005). However, a lack of persistence in perennial cool-season grasses has been observed because of high temperatures and limited moisture during the summer (Malinowski *et al.*, 2003; Gillen and Berg, 2005). Perennial or over-seeded annual cool-season pastures grown in cool- and warm-season crop sequences can also extend the period of active forage production (Belesky and Fedders, 1995) and increase both cool-season and year-round forage and livestock production (Fribourg and Overton, 1979; Joost *et al.*, 1986; Gates *et al.*, 1999). Much of the research on warm- and cool-season grass mixtures has focused on cool-season grass mixtures with bermudagrass [*Cynodon dactylon* (L.) Pers.] or bahiagrass (*Paspalum notatum* Flügge) (Decker *et al.*, 1974; Utley *et al.*, 1976; Gates *et al.*, 1999) and competition from these improved warm-season grasses may exacerbate problems of persistence in companion cool-season species (Hoveland *et al.*, 1978; Bouton *et al.*, 2001).

Little research attention has been given to the viability of the integration of cool-season grasses into low-productivity warm-season pastures, derived from degraded rangeland, or from natural regeneration on abandoned crop land that is typical of pasture on many limited-resource farms in the southern Great Plains. Unimproved pasture may offer a less competitive environment for over-seeded cool-season species than encountered in mixtures with more aggressive warm-season species. Over-seeding cool-season grasses into unimproved warm-season pastures may, therefore, offer a means of increasing cool-season herbage production that is particularly suited to time and equipment constraints experienced by many limited-resource livestock producers. In addition, by using no-till seeding techniques and avoiding cultivation of existing pasture, soil erosion risk may be minimized (Raffaelle *et al.*, 1997). The objectives of this study were to evaluate the productivity and persistence of a range of cool-season grasses sown either as a complement to, or replacement for, unimproved warm-season pasture and to measure the impact on forage output of different establishment methods and prior cropping practices.

Materials and methods

The experiment was conducted during four growing seasons, 2002–2005, on a Coyle-series clay loam (fine-loamy siliceous thermic Udic Arguistoll), 6 km S of Langston, OK at 35° 53′ N, 97° 15′ W. Prior to imposing treatments, the soil pH was 6·1, soil nitrate-N content was 9 kg ha^{-1}, the phosphorus index (Mehlich 3) was 10 and the potassium index was 226. Temperatures during the experiment were obtained from a weather station at the site, and rainfall estimates were derived as a mean of rainfall at Guthrie, OK (19 km west of the site) and Perkins, OK (16 km east of the site). Standardized rainfall and temperature data were combined to create an aridity index (Hollinger *et al.*, 2001) that shows the variation in temperature and dryness, relative to long-term average conditions, throughout the experiment.

Six cool-season grass species; a creeping wheatgrass (*Elytrigia repens L.*) × bluebunch wheatgrass [*Pseudoroegneria spicata* (Pursh)] hybrid, cv Newhy (species CWG), Italian ryegrass (*Lolium multiflorum* Lam) cv Marshall (species IRG), intermediate wheatgrass [*Elytrigia intermedia* (Host) Nevski] cv Luna (species IWG), smooth brome (*Bromus inermis* Leyss.) cv Lincoln (species SB), tall fescue (*Festuca arundinacea* Schreb) cv Kentucky 31 (E+) (species TF) and tall wheatgrass [*Elytrigia elongata* (Host) Nevski] cv Jose (species TWG) were established by each of three methods: by seeding into ground clean tilled from unimproved pasture (treatment CULT), by no-till sowing into stubble of Korean lespedeza [*Kummerowia stipulacea* (Maxim) Makino] (treatment LES) or by no-till over-sowing of dormant unimproved warm-season pasture (treatment PAS). The existing pasture comprised a mixture of predominantly warm-season grass species, including sideoats grama (*Bouteloua curtipendula* Michx.), splitbeard bluestem (*Andropogon ternarius* Michx.), little bluestem [*Schizachyrium scoparium* (Michx.) Nash], big bluestem (*Andropogon gerardii* Vitman), switchgrass (*Panicum virgatum* L.), old field threeawn (*Aristida oligantha* Michx.), Florida paspalum (*Paspalum floridanum* Michx.), Scribner's panicum (*Panicum oligosanthes* Schult.) and Carolina joint-tail (*Coelorachis cylindrica* Michx.). The pasture had been managed for hay production for over 10 years prior to the experiment. A no-till seeder (Landpride, Salina, KS, USA) with 75-mm inter-row-spacing was used for sowing in all cases, on plots which were 4·42 m × 1·22 m. Prior to drilling into pasture or following Korean lespedeza, each area was trimmed using a sickle-bar mower to leave a stubble of approximately 5 cm. The no-till drill was also used for seeding on cultivated ground, following seedbed preparation by two passes with a rotatiller. Seed rates for grass species TF and IRG were, respectively, 31 and 33 kg ha^{-1}, grass species SB was sown at 16 kg ha^{-1}, and grass species TWG, IWG and CWG were all sown at 20 kg ha^{-1}. Seeding depth in all instances was adjusted to 13–19 mm. In addition to cool-season grass seeding treatments, an unsown treatment was included for each establishment method to provide a total of twenty-one grass-seeding × establishment method treatment combinations, each of which was replicated four times.

Cool-season grasses were initially sown on 26 September, 2001. Italian ryegrass was resown in the autumn of 2002, 2003 and 2004, at a seed rate of 33 kg ha^{-1}on each occasion, using the no-till seeder as described above, except that no further cultivation was made on clean-tilled plots. Korean lespedeza was surface-broadcast at 20 kg ha^{-1} in April 2002 to augment stands that had been sown to Korean lespedeza in the previous year.

Nitrogen fertilizer was applied as urea to all plots at 25 kg ha^{-1} in the autumn of each year from 2001 to 2004, following emergence of grass species IRG. A further 50 kg N ha^{-1} was applied to plots in mid-February of each year from 2002 to 2005. Based on the soil analyses, phosphorus was applied as triple superphosphate at 60 kg P_2O_5 ha^{-1} in the spring of 2002 and at 50 kg P_2O_5 ha^{-1} in the springs of 2003, 2004 and 2005.

Measurements

Emergence and establishment of the cool-season grasses were measured in the autumn of 2001 and the progression of cool-season grass swards was evaluated by plant counts each spring throughout the life of the experiment and by tiller counts in the springs of 2003 and 2005. Emergence of Korean lespedeza was measured each year in late March or early April. On each occasion, plant counts were made in duplicate using 15 cm × 15 cm quadrats placed at random in each plot. Estimates of seed deposition of Korean lespedeza were made at the end of the growing seasons of 2001 and 2002. In 2001, seed was collected directly from the soil surface using a hand-operated vacuum cleaner. Seeds deposited within eight randomly sited 15 cm × 15 cm sample areas were manually separated and counted. In 2002, to distinguish seed produced in 2002 from any residual seed produced in 2001, seeds were collected and counted directly in 14·6-cm diameter Petri dishes lined with paper treated with waterproof adhesive to trap seeds. One Petri dish was sampled within each grass subplot to provide a total of twenty-eight samples over four replicates.

Estimates of herbage yield were made by clipping an area of 4·42 m × 0·86 m in each plot, using a sickle-bar mower (Troybilt, Troy, NY, USA) set to a clipping height of 4 cm above the soil surface. Initial harvests were taken on 30 May, 19 May, 17 May and 19 May in 2002, 2003, 2004 and 2005 respectively. Subsequent harvests were taken when regrowth reached a height of 15–18 cm. Two estimates of regrowth were made in 2002, 2004 and 2005 while a single regrowth harvest was taken in 2003.

Following clipping, harvested material was weighed in the field and a sample of approximately 200 g was taken from each plot for hand-separation of sown cool-season grasses, other grasses, Korean lespedeza and forbs. These components were dried separately in a forced-draft oven at 60°C for a minimum of 48 h for estimation of the proportions of components in the dry matter (DM) and of the total-sample DM yield. After drying and weighing, the samples were reconstituted and ground in a Wiley mill, through a 1-mm screen. The effect of treatment on herbage quality was assessed by measuring the concentrations of acid-detergent fibre (ADF), neutral-detergent fibre (NDF) and total N of the dried samples. Total N concentration was estimated by colorimetric analysis in a Technicon continuous flow autoanalyzer (Technicon Industrial Systems, Tarrytown, NY, USA) following extraction by standard micro-Kjeldahl procedures (AOAC, 1990). The concentrations of ADF and NDF were determined using the filter bag technique (ANKOM Technology, Macedon, NY, USA).

Statistical analysis

The effects of species of cool-season grasses and method of establishment on yields of total herbage and its components in individual years, and accumulated over 4 years, were analysed as a split plot (GENSTAT, 2005). ANOVA with repeated measures was used to evaluate changes in plant and tiller densities of cool-season grasses during the experiment (GENSTAT, 2005). Mean separations were made by Fisher's protected least significant difference ($\alpha = 0{\cdot}05$).

Results

Amounts and distribution of rainfall varied widely among years (Figure 1). The rainfall in July in 2003 was only 0·21 of the 30-year average and this was reflected in the limited growth of herbage during the summer period, and resulted in only two harvests in

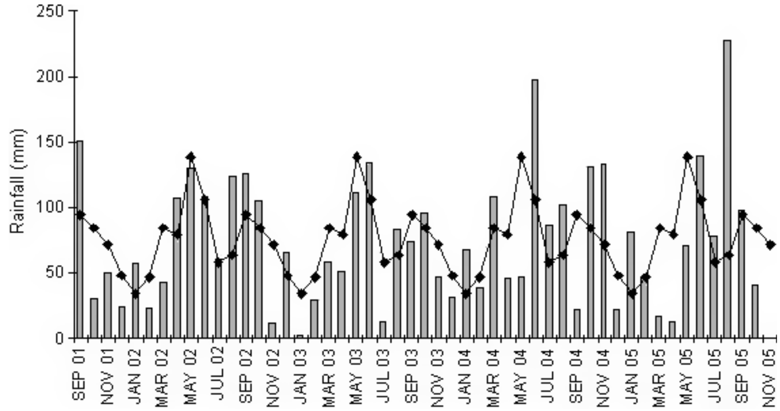

Figure 1 Monthly rainfall (mm) for the field site at Langston, Oklahoma for 2001, 2002, 2003, 2004 and 2005, and the 30-year average (◆) for each month.

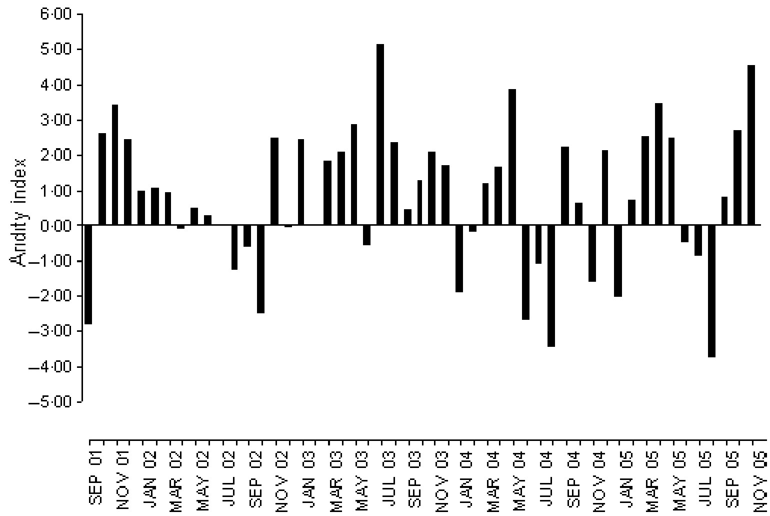

Figure 2 Monthly aridity index for the field site at Langston, Oklahoma for 2001, 2002, 2003, 2004 and 2005. [Aridity index; positive values indicate warmer or drier conditions (more arid), negative values indicate cooler or wetter conditions (less arid) than long-term (30-year) average.]

2003, rather than three in 2002, 2004 and 2005. Cumulative amounts of rainfall during the spring growing season from February to May for 2002, 2003, 2004 and 2005 were proportionally 0·86, 0·72, 0·68 and 0·41, respectively, of the 30-year average, and this is reflected in an increased aridity index for these months (Figure 2). Greater than average rainfall in June to August in 2004 and 2005 was associated with lower temperatures in July and August, which reduced the aridity index and resulted in greater summer growth of herbage than in the first 2 years of the experiment.

Establishment of cool-season grasses

In all perennial species, plant density declined throughout the experiment (Figure 3a). A significant ($P < 0{\cdot}05$) year × species interaction indicated that the decline in plant density was greater in species TF and wheatgrasses than in species SB. A similar response was evident in changes in tiller density between 2003 and 2005 (Figure 3b). Tiller production was insufficient in all perennial species to compensate for losses in plant numbers. The plant density achieved with annual re-sowing of species IRG ranged from 470 to 510 plants m^{-2} in all years except 2004, in which, for no clear reason, there was a significantly lower plant density of 190 plants m^{-2}. Tiller density of species IRG averaged 1810 and 1890 tillers m^{-2} in 2003 and 2005 respectively, reflecting the satisfactory plant densities in each of these years.

There was no difference in response among grass species to method of establishment. Mean plant density in November 2001 was greater ($P < 0{\cdot}05$) when cool-season grasses were established in Korean lespedeza stubble (544 plants m^{-2}) than when established in the CULT or PAS treatments (406 and 411 plants m^{-2} respectively). However, decline in plant density over the life of the experiment was similar among the establishment methods with no significant ($P > 0{\cdot}05$) year × establishment method interaction (Figure 3c).

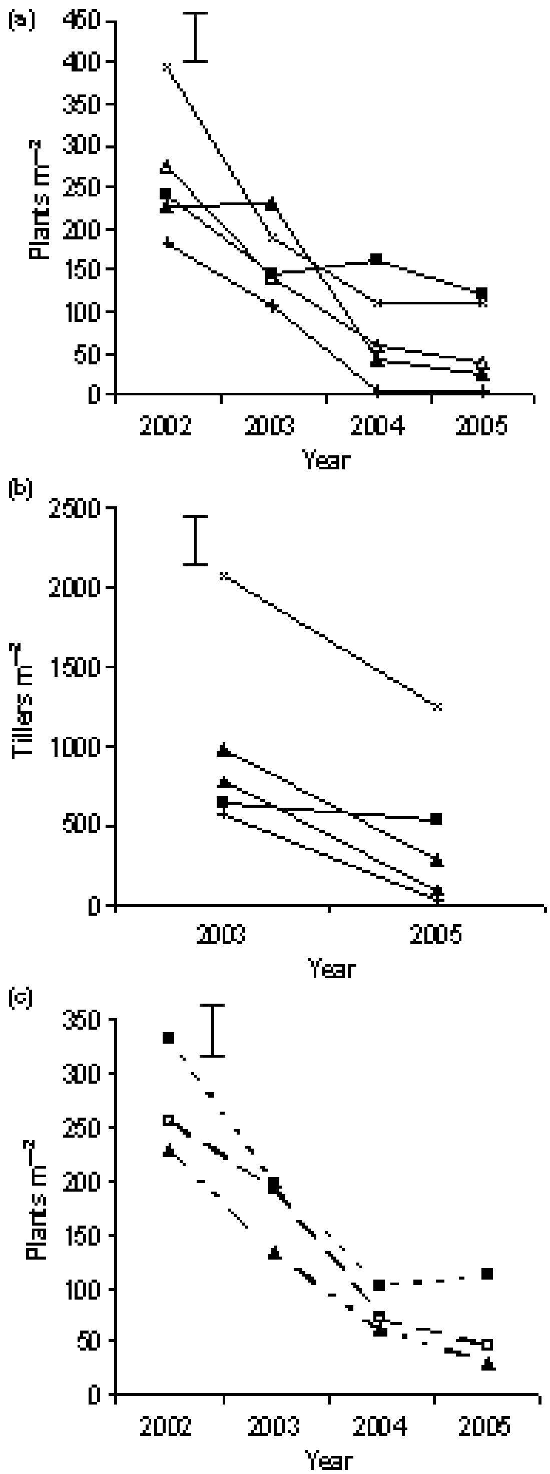

Figure 3 (a) Progression of plant density of perennial cool-season grass species between 2002 and 2005 and (b) progression of tiller counts of perennial cool-season grasses between 2003 and 2005. Grass species are: creeping wheatgrass hybrid (CWG, + - +), intermediate wheatgrass (IWG, ▲ - ▲), smooth brome (SB, ■ - ■), tall fescue (TF, × - ×) and tall wheatgrass (TWG, Δ - Δ). Figure 3 (c) progression of plant density of perennial cool-season grasses, according to method of establishment; conventional tillage and sowing (CULT, □ - □), no-till sowing into stubble of Korean lespedeza (LES, ■ - ■) and no-till sowing into undisturbed, unimproved warm-season pasture (PAS, ▲ - ▲). Vertical bars indicate least significant difference at $P < 0{\cdot}05$ among treatments.

Herbage production of cool-season grasses

Italian ryegrass produced the greatest 4-year cumulative cool-season DM yield of herbage (Figure 4) and, except when compared with species TF in 2004 and 2005, its year-by-year DM yield (Table 1) was greater than all the other perennial species. Among perennial cool-season grasses, species TWG had the highest DM yield of herbage in the first year of the experiment but its productivity declined in subsequent years, so that species TF had the highest DM yield of herbage over the 4-year life of the experiment, with an aggregate DM yield 0·54 greater than species TWG. Both cumulative and individual-year DM yields of species IWG and of CWG were significantly lower than those of species TWG and TF. The average decline in DM yield of cool-season grasses between the first and fourth years of the experiment was 0·92 and 0·93 in species TWG and IWG, respectively, 0·31 in species TF and 0·47 in species SB. Species CWG had no DM yield after three growing seasons.

Dry matter yields of all cool-season grass species were reduced when no-till seeded into existing warm-season pasture (treatment PAS). On average, the DM yield of cool-season grasses sown into existing pasture (treatment CULT) was 0·52 of that achieved when grasses were sown into cultivated ground or in mixture with Korean lespedeza (treatment LES). There was a significant cool-season grass × establishment method interaction in cumulative DM yield of herbage, which took the form of significantly greater DM yields of species TF and IRG when these were sown in mixture with Korean lespedeza (treatment LES), rather than in cultivated ground without warm-season legume (treatment CULT; Figure 4).

Herbage production of warm-season grasses

There were significant differences in the DM yield of warm-season grasses among the treatments establishing cool-season grass species (Table 2). Mean DM yields of warm-season grasses were greatest on treatments where existing pasture had received only minimal tillage during establishment of cool-season grasses (Table 2). Generally, higher DM yields of cool-season grasses were

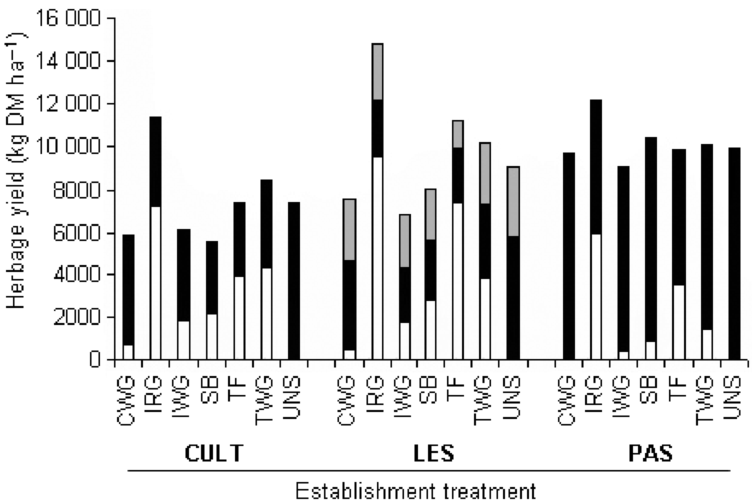

Figure 4 Cumulative total and component dry matter (DM) yields of herbage over 4 years (2002, 2003, 2004 and 2005) of cool-season grasses (CSG) and warm-season grasses (WSG) following introduction of cool-season grasses by conventional tillage and sowing (CULT), by no-till sowing into stubble of Korean lespedeza (LES) and by no-till sowing into undisturbed, unimproved warm-season pasture (PAS). Cool-season grass species are creeping wheatgrass hybrid (CWG), Italian ryegrass (IRG), intermediate wheatgrass (IWG), smooth brome (SB), tall fescue (TF) and tall wheatgrass (TWG). Treatments labelled UNS were not sown with cool-season grasses. Least significant differences, at $P < 0{\cdot}05$, for comparisons of CSG (□), WSG (■), LES (▩) components and the total yields for within-establishment methods were 1322, 1649, 739 and 1830 kg DM ha^{-1} respectively, and for among establishment method x cool-season grass species were 1493, 2297, n/a and 2274, respectively.

associated with lower DM yields of warm-season grasses with the decline in DM yield of warm-season grasses and increased DM yields of cool-season grasses not being significantly different among establishment methods. When expressed as a mean over years within establishment method, 0·74 of the variation in DM yield of warm-season grasses could be explained by a linear relationship which indicated a mean decline of 389 kg DM in yield of warm-season grasses for each 1000 kg DM increase in yield of cool-season grasses (Figure 5).

Establishment and herbage production of Korean lespedeza

Measures of seed deposition by monoculture Korean lespedeza, made in December 2001, indicated copious self-seeding; on average 10 200 seeds m^{-2} were deposited and *in vitro* germination tests showed that 89% of these were viable. Emergence counts in early April 2002 reflected the elevated seed supply with a mean of 3250 emerged seedlings m^{-2}. Self-thinning rapidly reduced this seedling population to a mean of 728 plants m^{-2} by the end of April and to 400 plants m^{-2} by the end of the growing season, with no significant difference among overseeding treatments. Seed deposition at the end of 2002 showed no significant difference between seeding treatments, with a mean of 3550 seeds m^{-2}. Mean re-established plant numbers were 2160 plants m^{-2} in 2003, 1853 plants m^{-2} in 2004 and 572 plants m^{-2} in 2005. The progression in plant density throughout the experiment is summarized in Figure 6. Herbage yield of Korean lespedeza was significantly smaller in 2003 (mean 180 kg DM ha^{-1}) than in 2002, 2004 or 2005 (means of 700, 980 and 700 kg DM ha^{-1} respectively). This difference was attributed to slow growth and extensive leaf-shedding resulting from the hot and dry conditions prevailing in June and July of 2003. In all years, DM yield of Korean lespedeza was least with species TF, and the 4-year cumulative DM yield was significantly ($P < 0{\cdot}05$) lower with species TF than on all other treatments (Table 3).

Total herbage production

Total DM yield of herbage (cool-season grasses + warm-season grasses + Korean lespedeza) over 4 years was greatest when cool-season grasses were sown into an existing warm-season pasture. The mean total DM yield on pasture-based treatments was 0·41 greater than that obtained when cool-season grasses were established on cultivated ground and 0·14 greater than the yield obtained when cool-season grasses were established in mixture with Korean lespedeza. Among cool-season grass species, only seeding with species IRG produced a total DM yield that was significantly greater than unsown treatments (Figure 4).

Table 1 Annual dry matter yields (kg ha^{-1}) in 2002, 2003, 2004 and 2005 of cool-season grass species sown into cultivated ground (CULT), no-till seeded into stubble of Korean lespedeza (LES) and into unimproved warm-season pasture (PAS).

Year	Establishment method	Cool-season grasses						Least significant difference at $P < 0{\cdot}05$
		CWG	IRG	IWG	SB	TF	TWG	
2002	CULT	430	3590	900	760	1560	2320	
	LES	430	3450	920	650	2010	2240	
	PAS	30	3090	320	190	1400	1300	
								825
2003	CULT	260	2210	790	900	1500	1430	
	LES	60	3330	720	1230	2040	1160	
	PAS	0	1490	60	310	970	130	
								474
2004	CULT	0	620	60	270	260	290	
	LES	0	940	80	460	1280	200	
	PAS	0	360	30	170	310	10	
								352
2005	CULT	0	830	70	190	560	230	
	LES	20	1870	70	460	2060	250	
	PAS	0	990	10	200	830	0	
								597

CWG, creeping wheatgrass hybrid; IRG, Italian ryegrass; IWG, intermediate wheatgrass; SB, smooth brome; TF, tall fescue; TWG, tall wheatgrass.

Table 2 Annual dry matter yields (kg ha^{-1}) of unimproved warm-season pasture following over-seeding of cool-season grass species into cultivated ground (CULT), no-till seeded into stubble of Korean lespedeza (LES) and into warm-season pasture (PAS).

Year	Establishment method	Cool-season grasses							Least significant difference at $P < 0{\cdot}05$
		CWG	IRG	IWG	SB	TF	TWG	UNS	
2002	CULT	650	250	620	510	410	450	1280	
	LES	810	360	390	560	240	370	910	
	PAS	2650	1410	2580	2950	1410	1890	3380	
									831
2003	CULT	1030	570	750	620	850	760	2140	
	LES	850	470	390	480	610	860	1470	
	PAS	2070	970	1620	2090	1250	1870	2100	
									548
2004	CULT	1870	2090	1630	1260	1400	1490	2540	
	LES	1270	1080	930	780	1100	1180	1540	
	PAS	3120	2650	2640	2970	2510	3080	2880	
									1018
2005	CULT	1530	1210	1330	1020	910	1450	1470	
	LES	1190	650	850	940	580	1070	1820	
	PAS	1820	1220	1790	1550	1210	1820	1590	
									660

CWG, creeping wheatgrass hybrid; IRG, Italian ryegrass; IWG, intermediate wheatgrass; SB, smooth brome; TF, tall fescue; TWG, tall wheatgrass. UNS is no cool-season over-seeding.

Herbage production in early-season

Dry matter yields in early-season (first harvest) declined over the life of the experiment (Figure 7) but this decline was not attributable solely to a reduction in the contribution of cool-season grasses to DM yield, as the yield from unsown pasture also diminished, from 2170 kg DM ha^{-1} in 2002 to 240 kg DM ha^{-1} in 2005.

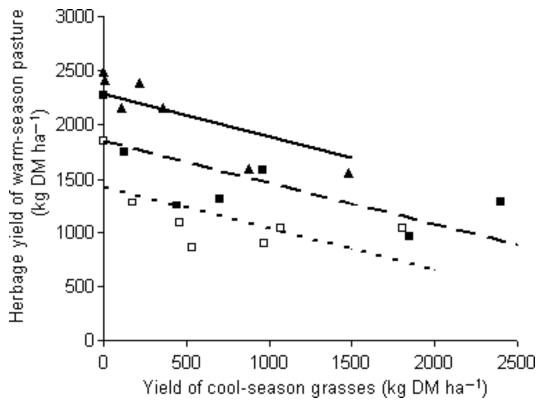

Figure 5 Relationship between annual dry matter (DM) yield of cool-season grasses (CSG) and DM yield of warm-season pasture (WSF, warm-season grasses + Korean lespedeza) in a cool-season–warm-season pasture, according to CSG establishment method; conventional tillage and sowing (CULT, □ - □), no-till sowing into stubble of Korean lespedeza (LES, ■ - ■) and no-till sowing into undisturbed warm-season pasture (PAS,▲ - ▲). Relationships are: WSF_{CULT} = 1424–0·389 CSG; WSF_{LES} = 1850–0·389 CSG; WSF_{PAS} = 2278–0·389 CSG (r^2 = 0·74).

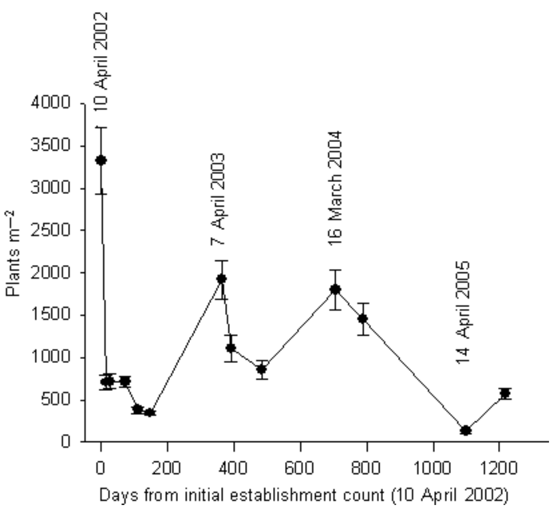

Figure 6 Progression of Korean lespedeza plant counts from 2002 to 2005. Vertical bars indicate standard error of mean at each observation.

The decline in DM yield may have reflected a decrease in rainfall from February to May, at 0·86, 0·72, 0·68 and 0. 41 in 2002, 2004, 2004 and 2005, respectively, of the 30-year average for the same months, although DM yields of species TF and IRG were greater in 2005 than 2004, in spite of the lower rainfall in the spring of 2005.

Throughout the experiment, only species IRG and TF had greater DM yields ($P < 0{\cdot}05$) than undisturbed pasture at the first harvest of the year (Figure 7).

Production of forbs

Predominant forbs were peppergrass [*Lepidium virginicum* L., scurf pea (*Psoralidium tenuiflorum* (Pursh) Rydb], daisy fleabane (*Erigeron strigosus* Muhl. Ex Willd), poorjoe (*Diodia teres* Walter) and antelopehorn milkweed (*Asclepias viridis* Walter). Cumulative DM yield of forbs was greater on treatment PAS than on the CULT or LES treatments. Dry matter yield of forbs was least on species IRG, TF and SB and greatest on species CWG and UNS (Table 4). On average over 4 years the yield of forbs was 536 kg DM ha^{-1} at the early-season harvest in May, compared with a mean of 204 kg DM ha^{-1} throughout the remainder of the year. Mean annual DM yield of forbs declined with increased DM yield of cool-season grasses at an average of 0·28 (s.e.m, 0·044) kg DM of forbs for each 1·0 kg increase in DM yield of cool-season grasses (r^2 = 0·67) and there was no significant difference among establishment methods. Higher DM yields of warm-season grasses, in contrast, were associated with higher DM yields of forbs (r^2 = 0·44) (Figure 8) but this probably reflects the effect of a lower DM yield of cool-season grasses on both components rather than an interaction between them.

Re-establishment of warm-season grasses

Some re-establishment of warm-season grasses occurred in the CULT and LES treatments during the experiment. Re-establishment was faster on the CULT than on the LES treatment, and by the third year after sowing there was a significant difference in DM yield of warm-season grasses on these treatments (Table 2). In 2002, 2003 and 2004 on plots sown with cool-season grasses, the mean DM yields of warm-season grasses of CULT and LES treatments were significantly lower than on the no-till drilled pasture treatment, indicating that warm-season grasses in disturbed ground had not fully regained their potential for yield even after 3 years of recovery. On plots that were not sown with cool-season grasses, there was a mean 2100 kg DM ha^{-1} reduction in DM yield of warm-season grasses on treatment CULT, compared with the PAS treatment, during the first year but differences in subsequent years were not significant.

Effects of cool-season grass species and establishment method on herbage quality

Over 4 years mean crude protein (CP, N concentration × 6·25) concentration of herbage at first harvest increased to 138 g kg^{-1}DM, compared with unseeded

Table 3 Annual and 4-year (2002, 2003, 2004 and 2005) total dry matter yields (kg ha^{-1}) of Korean lespedeza according to cool-season grass over-seeding species.

Year	Cool-season grasses							Least significant difference at $P < 0{\cdot}05$
	CWG	IRG	IWG	SB	TF	TWG	UNS	
2002	750	540	530	840	480	640	1140	305
2003	230	120	200	150	60	190	340	92
2004	1100	1150	940	930	530	1110	1080	231
2005	820	810	800	560	250	890	790	284
4-year total	2990	2620	2470	2480	1320	2830	3350	739

CWG, creeping wheatgrass hybrid; IRG, Italian ryegrass; IWG, intermediate wheatgrass; SB, smooth brome; TF, tall fescue; TWG, tall wheatgrass. UNS is no cool-season over-seeding.

plots (119 g kg^{-1} DM), by over-seeding with wheatgrasses and smooth brome. Plots sown with tall fescue or Italian ryegrass showed no increase in CP concentration of herbage compared with unseeded plots. There was no significant effect of establishment method on CP concentration at the first harvest, but at the second harvest the CP concentration of herbage was significantly higher on the LES treatment (179 g kg^{-1} DM), compared with the CULT and PAS treatments (99 and 112 g kg^{-1} DM, respectively). The effects of cool-season grasses and establishment method on ADF (mean 418 g kg^{-1}DM) and NDF (mean 578 g kg^{-1}DM) concentrations were small and differences among treatments were not significant.

Discussion

Cool-season grasses can be established by no-till drilling into dormant, or nearly dormant, unimproved warm-season pasture without suppression by herbicides of resident pasture. However, established populations of cool-season grasses were greater when no-till drilling into stubble of Korean lespedeza occurred or when sown into tilled ground, and this is consistent with other work that has demonstrated that establishment of over-seeded grasses may be enhanced by suppression or destruction of resident vegetation (Samson and Moser, 1982; Cuomo *et al.*, 1999). Use of herbicides was avoided in this experiment to conform with a need to identify low-input approaches to pasture improvement and with a wish to minimize damage to existing pasture. Total DM yields of cool-season grasses established in existing pasture were significantly smaller than the DM yields obtained when cool-season grasses were established by conventional tillage and sowing and this is also consistent with other work (Utley *et al.*, 1976; Cuomo and Blouin, 1997). Sustained productivity of cool-season perennial grasses was poor. While this may be attributed to some degree to limited spring rainfall in all years, declining plant stands in all perennial species clearly showed an underlying lack of persistence. The mean rates of reduction in plant and tiller populations over the 4-year life of the experiment, however, were similar, irrespective of establishment method. This is consistent with the observations reported by Samson and Moser (1982) and Bellotti and Blair (1989), suggesting that establishment method *per se* does not greatly influence the persistence of cool-season grasses. The poor long-term performance of perennial cool-season grasses reported here is probably a reflection of a less-favoured site and exposure to hot and dry conditions in summer (Gates *et al.*, 1999), but represents a serious constraint to the economic viability of introducing cool-season grasses into a low-productivity system. Italian ryegrass was the greatest-yielding cool-season grass among those tested but, as IRG is an annual grass, any benefits in DM yield compared with perennial species must be discounted by the cost of the reseeding necessary to ensure continued production from year to year. Italian ryegrass can be managed to self-reseed but this may also carry a cost in terms of a penalty in yield arising from the early harvest or partial harvest that is necessary to ensure production of sufficient seed for re-establishment.

Increases in DM yield of herbage of the IRG and TF species at the initial harvest in each year demonstrated that some improvement in seasonal distribution of forage is possible with introduction of cool-season grasses into unimproved pasture. An initial harvest earlier than mid-May would have increased the importance of yields of cool-season grasses relative to warm-season grasses but it may also have led to a decrease in the harvestable yield. This is illustrated by the DM accumulation rates of IRG cv. Marshall, grown under conditions similar to those reported here and which were 96 kg ha^{-1} d^{-1} in May 2003 and 41 kg ha^{-1} d^{-1} in May 2004 (P.W. Bartholomew, unpublished data). If the initial harvest in the experiments reported here had been advanced to early May (16 days earlier than the actual harvest) in each of these years, DM yield of IRG would have been reduced proportionately to an estimated 0·34 and 0·00 of the yield at the mid-May

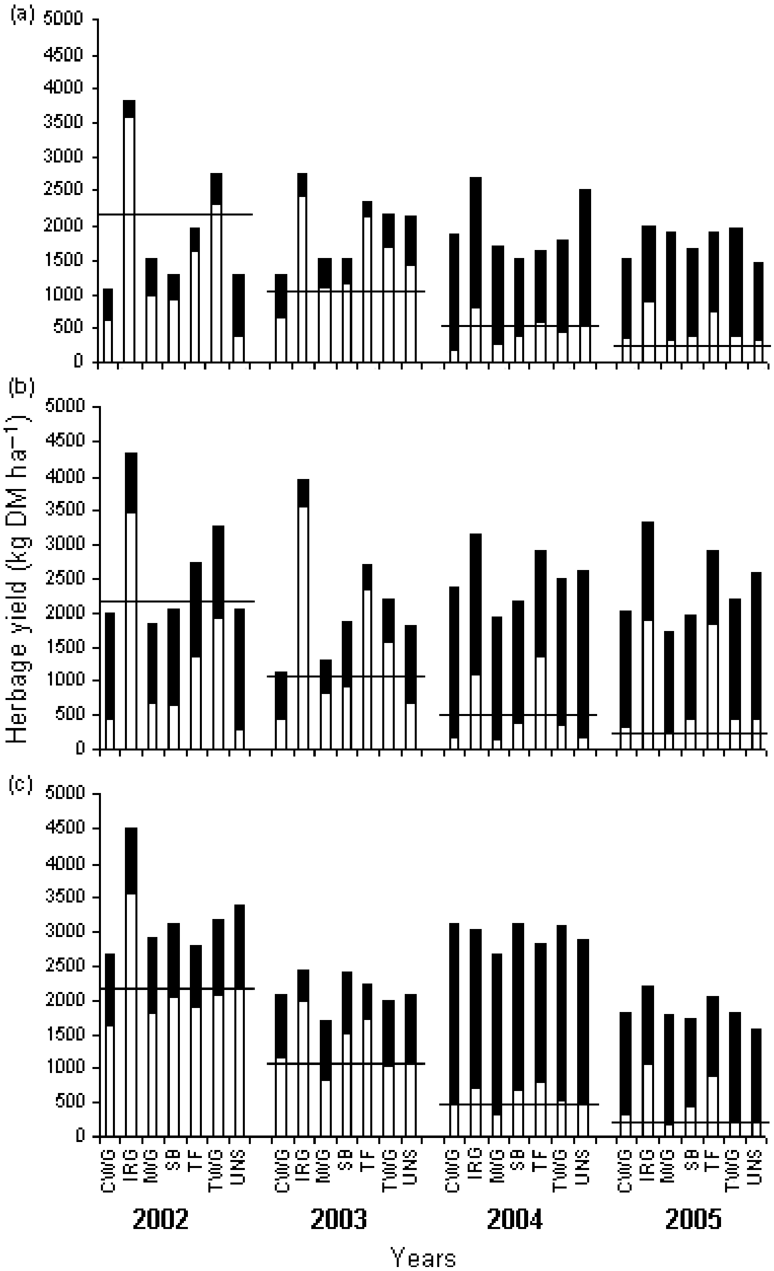

Figure 7 Seasonal distribution of dry matter (DM) yield of herbage, according to cool-season grass species and establishment method, mean annual yield 2002–2005. 'Early-season' is harvest in latter half of May (□) and 'Late-season' is harvests after the end of May (■). Establishment methods are (a) by introduction of cool-season grasses by conventional tillage and sowing (CULT), (b) by no-till sowing into stubble of Korean lespedeza (LES) and (c) by no-till sowing into undisturbed, unimproved warm-season pasture (PAS). Cool-season grass species are creeping wheatgrass hybrid (CWG), Italian ryegrass (IRG), intermediate wheatgrass (IWG), smooth brome (SB), tall fescue (TF) and tall wheatgrass (TWG). Treatments labelled UNS were not sown with cool-season grasses. Horizontal line indicates mean early-season DM yield of unmodified warm-season pasture in each year. Least significant differences at $P < 0{\cdot}05$ for 2002, 2003, 2004 and 2005 were, for DM yield in early season, 1062, 567, 458 and 456 kg DM ha^{-1}, respectively, and for total DM yield of herbage were 1287, 853, 828 and 506 kg DM ha^{-1}, respectively.

harvest. The scope for earlier harvests is likely to be limited in low-productivity systems.

Harvest of cool-season grasses in mid- to late May was well-timed for release of Korean lespedeza for early summer regrowth. In 3 of the 4 years of the experiments, Korean lespedeza made a significant contribution to DM yield of herbage. Low DM yields of Korean lespedeza obtained in 2003 emphasize the need for adequate moisture following the harvest of cool-season grasses. Self-reseeding of Korean lespedeza occurred in all years, although an intermediate harvest (2002 and 2004) and poor mid-summer growth (2003) restricted the number of flowering branches that produced viable seed. Seed yields estimated from seed deposition measures were between 0·07 and 0·21 of the highest yields reported by Davis *et al.* (1994) with optimal management of Korean lespedeza grown for seed production. The presence of Korean lespedeza in mixtures stimulated the production of IRG and TF species but, in comparison with cultivated plots over the life of the experiment, retarded the recovery of warm-season grasses, which is consistent with the effects of a

Table 4 Effects of method of establishment and cool-season grass species on the cumulative total dry matter (DM) yield of forbs over 4 years (2002–2005).

		DM yield of forbs (kg ha^{-1})
Method of establishment	CULT	2700
	LES	2680
	PAS	3470
	Least significant difference at $P < 0{\cdot}05$	404
Cool-season grass treatment	CWG	3900
	IRG	2030
	IWG	3350
	SB	2220
	TF	2090
	TWG	2940
	UNS	4110
	Least significant difference at $P < 0{\cdot}05$	617

CWG, creeping wheatgrass hybrid; IRG, Italian ryegrass; IWG, intermediate wheatgrass; SB, smooth brome; TF, tall fescue; TWG, tall wheatgrass. UNS is no cool-season over-seeding. Method of establishment: cool-season grass species sown into cultivated ground (CULT) or, no-till seeded into stubble of Korean lespedeza (LES) or into warm-season pasture (PAS).

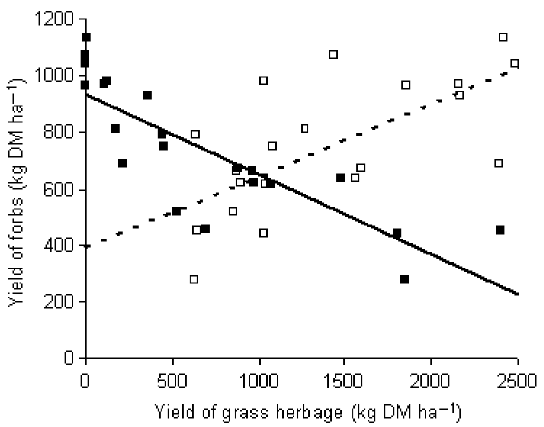

Figure 8 Average annual effect of dry matter (DM) yields of cool- (CSG, ■) and warm- (WSG, □) season grasses on DM yield of forbs (Forb) in a cool-season–warm-season forage sequence. Forb = 933–0·283CSG (r^2 = 0·67); Forb = 388 + 0·255WSG (r^2 = 0·44).

contribution from legume-fixed N and of competition (from both Korean lespedeza and cool-season grasses) with warm-season grasses. Inclusion of Korean lespedeza in the sequence led to a measurable increase in the concentration of N in herbage.

Annual DM yields of grasses from unsown pasture, at a mean of 2500 kg ha^{-1}, were comparable to those reported from similar pastures (Berg, 1995; Gillen and Berg, 1998) in a low-input marginal environment. In these conditions, a significant increase in carrying capacity might be expected from relatively small yields of cool-season grasses. In fact, the benefit of the introduction of cool-season grasses into warm-season pasture, either as a complement or as a replacement, was generally much less than the DM yields of cool-season grasses might imply. Figure 9 is derived from data presented in Figure 5 and shows, for each method of establishment, the change in annual DM yield of herbage resulting from the inclusion of cool-season grasses in a mixture of cool- and warm-season grasses, compared with undisturbed warm-season pasture, according to the DM yield of cool-season grasses. Only treatments that retained existing warm-season pasture consistently showed an increase in DM yield compared with undisturbed pasture as a result of sowing cool-season grasses. When cool-season grasses were sown into cultivated ground or into stubble of Korean lespedeza, there was a threshold of DM yield for cool-season grasses below which the mixture of cool- and warm-season grasses failed to match the DM yield of undisturbed warm-season pasture. In the case of clean-tillage, this threshold was approximately 1400 kg ha^{-1} year^{-1} and, when cool-season grass was sown into stubble of Korean lespedeza, a minimum threshold of 700 kg ha^{-1} year^{-1} of DM yield of cool-season grasses was necessary before the annual DM yield of the mixture was equal to that of undisturbed warm-season pasture. The rate of reduction of DM yield

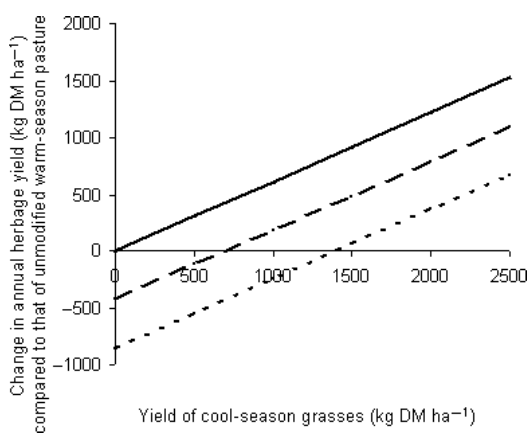

Figure 9 Calculated change in annual drymatter (DM) yield of herbage (compared with unmodified warm-season pasture) resulting from inclusion of cool-season grasses in a warm-season pasture, according to DM yield of cool-season grasses and establishment method; conventional tillage and sowing (CULT, ...), no-till sowing into stubble of Korean lespedeza (LES, - - - -) no-till sowing into undisturbed warm-season pasture (PAS, ————).

of warm-season grasses, estimated at 0·39 kg kg^{-1} increase in cool-season grasses, is comparable to the rates derived from Joost *et al.* (1986) (0·39 kg kg^{-1}) and Fribourg and Overton (1973) (0·35 kg kg^{-1}) although it should be noted that the DM yields reported by these authors were between two and three times greater than those found in this study. Higher yields of cool-season grasses also reduced yields of forbs and this may represent an additional contribution of cool-season grasses to the overall productivity of the farming system through suppression of weed growth in spring.

The results demonstrate that the tillage of existing warm-season grasses to sow cool-season grasses is likely to reduce the overall carrying capacity of a pasture. Re-establishment of warm-season grass pasture will occur following cultivation but recovery may be prolonged. In mixtures with cool-season grasses or warm-season legumes, DM yields of re-established warm-season grasses did not regain the levels achieved in uncultivated ground until the fourth growing season after cultivation. The results emphasize the importance of successful establishment of cool-season grasses, as failure of cool-season grasses to establish will exacerbate the reduction in herbage production that results from destruction of warm-season pastures. The probability of failure of establishment in cool-season grasses is poorly quantified for the southern Great Plains but Ries and Hofmann (1996) provided an estimate of probability of risk of failure of 0·32–0·55 in the northern Great Plains. The impact of failure of establishment on the viability of a programme of planting of cool-season grasses probably merits greater attention than it has so far received.

While it is arguable that in farming systems in the southern Great Plains, cool-season herbage is of greater value than warm-season herbage, because of the relative scarcity and greater need for the former, in a limited-resource environment where forage production is less than nutrient requirements of livestock, management that results in a reduction in annual carrying capacity seems counterproductive even if production of cool-season grasses is increased. A nutrient deficit in summer and autumn is likely to increase the pressure on supply of cool-season grasses, as the potential for stockpiling, or other methods of conserving herbage, will be reduced. However, in systems where soil-moisture availability limits the possibility of relay-cropping of warm- and cool-season grasses, replacement of existing warm-season pasture by cool-season grasses may be justified by a reduction in cost for cool-season feeding resulting from an extended grazing season.

Conclusion

Establishment of cool-season grasses in dormant or nearly dormant warm-season pasture is possible without herbicide suppression of existing vegetation but is less successful than planting in cultivated ground. Inclusion of Korean lespedeza in a cool- and warm-season grass sequence can make a useful contribution to annual DM yields, can improve seasonal distribution of herbage production and increase the concentration of N in herbage. If existing warm-season pasture is removed by tillage to establish cool-season grasses, the year-round herbage production from the resulting pasture is likely to be less than that of warm-season pasture that has been over-seeded with cool-season grasses without tilling, or that is undisturbed. In conditions typical of those found in limited-resource farms in the southern Great Plains, cool-season perennial grasses may not be a viable long-term addition to, or replacement for, unimproved warm-season pasture because of their limited persistence and low productivity. Annually sown Italian ryegrass is a productive alternative cool-season forage for these circumstances.

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Mention of trademark names does not represent an endorsement over other comparable products by the USDA-ARS.

References

AOAC. (1990) *Official methods of analysis*, 15th edn. Arlington, VA, USA: Association of Official Analytical Chemists.

Belesky D.P. and Fedders J.M. (1995) Comparative growth analysis of cool- and warm-season grasses in a cool-temperate environment. *Agronomy Journal*, **87**, 974–980.

Bellotti W.D. and Blair G.J. (1989) The influence of sowing method on perennial grass establishment. III Survival and growth of emerged seedlings. *Australian Journal of Agricultural Research*, **40**, 323–331.

Berg W.A. (1995) Response of a mixed native warm-season grass planting to nitrogen fertilization. *Journal of Range Management*, **48**, 64–67.

Bouton J.H., Gates R.N. and Hoveland C.S. (2001) Selection for persistence in endophyte-free Kentucky 31 tall fescue. *Crop Science*, **41**, 1026–1028.

Cathey H.M. (1990) *USDA Plant hardiness zone map*. USDA Miscellaneous Publication No. 1475. Washington, DC, USA: U.S. Department of Agriculture.

Cuomo G.J. and Blouin D.C. (1997) Annual ryegrass forage mass distribution as affected by sod-suppression and tillage. *Journal of Production Agriculture*, **10**, 256–260.

Cuomo G.J., Redfearn D.D., Beatty J.F., Anders R.A., Martin F.B. and Blouin D.C. (1999) Management of warm-season annual grass residue on annual ryegrass establishment and production. *Agronomy Journal*, **91**, 666–671.

Davis D.K., Mcgraw R.L. and Beuselinck P.R. (1994) Herbage and seed production of annual lespedezas as affected by harvest management. *Agronomy Journal*, **86**, 704–706.

Decker A.M., Retzer H.J. and Dudley F.R. (1974) Cool-season perennials vs cool-season annuals sod seeded into a bermudagrass sward. *Agronomy Journal*, **66**, 381–383.

Evers G.W., Redmon L.A. and Provin T.L. (2004) Comparison of Bermudagrass, Bahiagrass and Kikuyu-grass as a standing hay crop. *Crop Science*, **44**, 1370–1378.

Fribourg H.A. and Overton J.R. (1973) Forage production on bermudagrass sods overseeded with tall fescue and winter annual grasses. *Agronomy Journal*, **65**, 295–298.

Fribourg H.A. and Overton J.R. (1979) Persistence and productivity of tall fescue in bermudagrass sods subjected to different clipping managements. *Agronomy Journal*, **71**, 620–624.

Gates R.N., Hill G.M. and Bouton J.H. (1999) Wintering beef cattle on mixtures of 'Georgia 5' tall fescue and warm-season perennial grasses on coastal plain soils. *Journal of Production Agriculture*, **12**, 581–587.

Genstat (2005) *GenStat for Windows, Release 8.2.0.158*, 8th edn. Oxford, UK: VSN International Ltd.

Gillen R.L. and Berg W.A. (1998) Nitrogen fertilization of a native grass planting in western Oklahoma. *Journal of Range Management*, **51**, 436–441.

Gillen R.L. and Berg W.A. (2005) Response of perennial cool-season grasses to clipping in the southern plains. *Agronomy Journal*, **97**, 125–130.

Hollinger S.E., Ehler E.J. and Carlson R.E. (2001) Midwestern United States corn and soybean yield response to changing El Nino-Southern Oscillation conditions during the growing season. In: Kral D.M., Hatfield J.L, Volenec J.J. and Dick W.A. (eds) *Impacts of El Nino and climate variability on agriculture. ASA Special Publication 63*. pp. 31–54. Madison, WI, USA: American Society of Agronomy.

Hoppe R.A. and Banker D.E. (2006) *Structure and finances of U.S. farms: 2005 family farm report*. USDA Economic Research Service, Economic Information Bulletin No. 12, May 2006. Washington, DC, USA: United States Department of Agriculture.

Hoveland C.S., Mccormick R.F. Jr, Carden E.L., Rodriguez-Kabana R. and Shelton J.T. (1978) Maintaining tall fescue stands in association with bahiagrass. *Agronomy Journal*, **70**, 649–652.

Joost R.E., Friesner D.L., Mason L.F. and Allen M. (1986) Potential for year-round forage production using no-till in the lower south. *Proceedings of the American Forage and Grassland Conference 1986*, Lexington, KY, USA: American Forage and Grassland Council, pp. 253–257.

Malinowski D.P., Hopkins A.A., Pinchak W.E., Sij J.W. and Ansley R.J. (2003) Productivity and survival of defoliated wheatgrasses in the rolling plains of Texas. *Agronomy Journal*, **95**, 614–626.

Malinowski D.P., Zuo H., Kramp B.A., Muir J.P. and Pinchak W.E. (2005) Obligatory summer-dormant cool-season perennial grasses for semiarid environments of the southern Great Plains. *Agronomy Journal*, **97**, 147–154.

Northup B.K., Phillips W.A. and Mayeux H.S. (2005) A modified forage system for stocker production in the Southern Great Plains, USA. In: O'Mara F.P., Wilkins R.J., Mannetje L.'t, Lovett D.K., Rogers P.A.M. and Boland T.M. (eds) *Proceedings of XX International Grassland Congress, Dublin, Ireland*, p. 469. Wageningen, The Netherlands: Wageningen Academic Publishers.

Ojima D., Garcia L., Elgaali E., Miller K., Kittel T.G.F. and Lackett J. (1999) Potential climate change impacts on water resources in the Great Plains. *Journal of the American Water Resources Association*, **35**, 1443–1454.

Raffaelle J.B. Jr, Mcgregor K.C., Foster G.R. and Cullum R.F. (1997) Effect of narrow grass strips on conservation reserve land converted to cropland. *Transactions of the American Society of Agricultural Engineers*, **40**, 1581–1587.

Ramsey R., Doye D., Ward C., Mcgrann J., Falconer L. and Bevers S. (2005) Factors affecting beef cow-herd costs, production and profits. *Journal of Agricultural and Applied Economics*, **37**, 91–99.

Redmon L.A., Horn G.W., Krenzer E.G. Jr and Bernado D.J. (1995) A review of livestock grazing and wheat grain yield: boom or bust? *Agronomy Journal*, **87**, 137–147.

Ries R.E. and Hofmann L. (1996) Perennial grass establishment in relationship to seeding dates in the Northern Great Plains. *Journal of Range Management*, **49**, 504–508.

Rogers J. (2004) *Use these methods to reduce hay feeding costs*. Ag News & Views, September 2004. http://www.noble.org/ag/forage/reducehayfeedingcosts (last accessed 19 November 2007).

Samson J.F. and Moser L.E. (1982) Sod-seeding perennial grasses into eastern Nebraska pastures. *Agronomy Journal*, **74**, 1055–1060.

Utley P.R., Marchant W.H. and Mccormick W.C. (1976) Evaluation of annual grass forages in prepared seedbeds and over-seeded into perennial sods. *Journal of Animal Science*, **42**, 16–20.

Zhao W. and Khalil M.A.K. (1993) The relationship between precipitation and temperature over the contiguous United States. *Journal of Climate*, **6**, 1232–1236.